

Development of Light-Weight, Eco-Friendly E-Waste Plastic and Glass Fibre Reinforced Gypsum Composites for Sustainable Building Applications

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Abstract

Due to the growing problems with electronic waste (e-waste) disposal and the essential need for sustainable construction materials in infrastructure-rigid contexts, e-waste management in many developing countries is still largely informal, and materials are not adequately used, while at the same time the construction industry is heavily relying on resources intensive materials. This disconnection is seen as an opportunity to include waste flows into material supply chains. This research involves the creation and testing of gypsum based composites containing shredded source-defined e-waste plastic and glass fibre for non-structural building construction applications. Five compositions were designed and tested for compressive strength, density, flexural strength, and water absorption using the reported laboratory procedures. The results show that the incorporation of e-waste-plastics decreases the density and moisture absorption of the composite while the glass fibre reinforcement increases the mechanical performance of the composite. The nominal 15% plastic and 10% glass fibre formulation was selected as optimal because, among the five mixtures tested, it provided the highest compressive and flexural strengths together with the lowest density and water absorption. Compared with the pure gypsum control, it increased compressive strength by 33.1% (24.8 to 33.0 MPa) and flexural strength by 63.6% (6.6 to 10.8 MPa). In addition to material performance, the research is translated to a decentralized e-waste valorisation model, presenting a possible route for converting regional waste streams into construction-material feedstock. The results indicate a possible link between informal recycling practices and small-scale local material production, thereby supporting resource-efficiency and circular-economy transitions in Global South settings. Both empirical and conceptual insights into the role of material innovation as a bridge between waste management and construction systems are provided, with an upgradable pathway for sustainable use of materials for resource utilization.

1. Introduction

In the last few decades, the proliferation of electronic devices has led to an increase in electronic waste (e-waste), which is now considered as one of the fastest growing waste streams worldwide [1]. Recycling is generally not well developed in LMC countries, with only the higher value metals recovered from the plastics, and the polymeric fractions being either disposed or improperly managed [2,3]. It is readily observed that these e-waste polymers are not being used to their full potential; this is a loss of potentially valuable secondary resources, environmental contamination and health risks [4,5].

Meanwhile, the building and construction industry is a major user of raw materials in the world and a significant source of environmental impacts such as resource consumption and waste production [6]. Energy-intensive, resource intensive and vulnerable to market price fluctuations, construction materials such as concrete, bricks and timber can be difficult to access in regions with infrastructure constraints [7,8]. However, this does not seem to be the case in Nigeria where the demand often far outstrips material availability, thus further reinforcing the structural imbalance between material supply systems and development requirements.

Circular economy frameworks promote the re-introduction of waste streams into productive use cycles, emphasizing strategies such as material substitution, recycling and reuse to reduce environmental burdens and improve resource efficiency [9]. Recent studies show that the material and implementation questions remain separated: Georgeoi et al. [10] review the use of electrical and electronic waste mainly in concrete; Ramesh and Anbarasan [11] focus on the structural performance, fire resistance and durability of glass-fibre-reinforced gypsum panels; and Balti et al. [12] optimize a gypsum formulation containing paper waste and surfactant. These studies do not examine the combined use of shredded post-consumer e-waste plastic and purchased glass fibre in a gypsum matrix or connect the resulting physical and mechanical performance to a decentralized recovery pathway in an infrastructure-constrained setting.

Due to its low cost, ease of workability and relatively low embodied energy compared to cementitious binders, gypsum is commonly used in non-structural applications, such as interior partitions, ceiling boards and finishes [12,13]. Gypsum has low mechanical strength and is susceptible to moisture which limits its more extensive use in construction. Polymer particles and fibres may mitigate these limitations while enabling valorisation of e-waste plastic; in this study, the glass fibre was a purchased reinforcement rather than a recovered e-waste fraction.

Developing lightweight, sustainable building materials requires balancing density reduction with structural integrity. While calcined gypsum ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) offers excellent fire resistance and processability, its inherent brittleness limits its structural utility. Incorporating low-density e-waste plastic can reduce composite density; however, particulate polymer inclusions may act as stress concentrators that decrease flexural and compressive strength.

To mitigate this degradation, this study introduces glass fibre as a complementary reinforcement. The two additives operate through distinct mechanisms: e-waste plastic acts as a low-density particulate filler that reduces unit weight, while glass fibre serves as a linear reinforcing phase that bridges advancing cracks and transfers tensile stresses across matrix voids. The novelty of this work lies in evaluating this hybrid particulate-linear reinforcement system within a gypsum matrix.

Furthermore, physical testing alone provides limited visibility into internal stress distributions during loading. Finite Element Analysis (FEA) via ANSYS was therefore used as an exploratory numerical approach to visualise stress and strain distributions in simplified cube and prism models. The numerical model identifiers and formulation definitions are distinguished from the experimental sample IDs below.

Hence, this research work develops composites of gypsum reinforced with shredded source-defined e-waste plastic and glass fibres and evaluates their mechanical and physical performance through the reported laboratory tests. Besides physical and mechanical performance testing, this work introduces a decentralized e-waste valorization scheme that lays the foundation for the incorporation of informal waste streams into the manufacturing of construction materials in Nigeria. By combining material testing with a Nigeria-focused decentralized valorization scheme, the study addresses both the material-level and implementation gaps identified above.

2. Materials and Method

2.1 Equipment

Shredding machine (for e-waste plastic), Sieve shaker, Digital weighing scale, Mechanical mixer, Moulds (50 mm × 50 mm × 50 mm cubes for compressive testing and 40 mm × 40 mm × 160 mm prisms for flexural testing), Curing chamber, Universal testing machine (UTM), Water absorption testing setup, Oven (for drying), Flexural testing machine.

2.2 Gypsum

A commercially available calcined gypsum, typically found in granulated form under 1 mm in size, was refined further, for experimental use. The material was ball-milled, and particles finer than 100 μm were selected after sieving to ensure uniformity for analysis and testing. The chemical composition of the gypsum as determined by XRF analysis is presented in Table 1, and the gypsum moulding powder is shown in Fig. 1. The listed oxide and LOI values sum to 92.22%; the unreported balance was not identified in the available record.



Fig. 1 Gypsum moulding powder

Table 1 Chemical composition of gypsum determined by XRF analysis

Oxide (%)	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	SO ₃	Na ₂ O	K ₂ O	LOI
Gypsum	33.8	0.20	0.10	0.04	0.10	50.14	0.16	0.08	7.60

2.3 Electroplastic Waste

Post-consumer plastic was collected from discarded television casings and keyboard parts. The material was cleaned, dried, shredded and ground to an approximate particle-size range of 2-5 mm. No FTIR, DSC, TGA, Raman spectroscopy or XRF analysis was performed on the recovered plastic; therefore, its polymer and elemental composition was not confirmed. The material is consequently described throughout this paper as source-defined post-consumer e-waste plastic rather than being assigned to ABS, HIPS, PC or another polymer type. Results should be interpreted as specific to the feedstock tested, and compositional differences between e-waste streams may affect reproducibility.

Table 2 Source and preparation record for the e-waste plastic feedstock

Characteristic	Documented information	Purpose
Source items	Discarded television casings and keyboard parts	Defines the source category of the feedstock
Pre-treatment	Cleaned and dried	Records preparation before size reduction
Size reduction	Shredded and ground	Describes physical processing
Particle-size range	Approximately 2-5 mm	Defines the tested size range
Material designation	Source-defined post-consumer e-waste plastic	Avoids unsupported polymer-specific assignment
Polymer/elemental composition	Not determined instrumentally	Limits composition-based reproducibility

Table 3 *Characterization status and study boundary for the e-waste plastic feedstock*

Technique	Status for the e-waste plastic	Information not determined
FTIR	Not performed	Polymer functional groups
DSC	Not performed	Thermal transitions
TGA	Not performed	Thermal stability and decomposition
Raman spectroscopy	Not performed	Molecular structure
XRF	Not performed on the plastic feedstock	Elemental composition and additives
Study boundary	Results apply to the tested source-defined feedstock	Batch-to-batch compositional variability remains unquantified

2.4 Glass Fibre

The purchased glass fibre used in this study was light white, as shown in Fig. 2, and was chopped to approximately 6–12 mm as stated in Section 2.6. The available record did not include batch-specific measurements of fibre density, tensile strength, elastic modulus, thermal resistance, moisture sensitivity or coupling-agent treatment. Consequently, the values and behaviours discussed in references [14–16] are treated as general literature context rather than measured properties of the fibre batch used here. Potable tap water was used in the preparation of gypsum-based composites. The use of clean water is essential to prevent contamination that may adversely affect the hydration process.

**Fig. 2** *Glass fibre*

2.5 Mixture Proportion

There were five different mix designs in which the gypsum-based composites were developed, including a control sample (A) containing 0% e-waste plastic and 0% glass fibre. The other four formulations contained 90%, 85%, 80%, and 75% gypsum, 10% or 15% e-waste plastic, and 0%, 5%, or 10% glass fibre, as shown in Table 4. The objective of this mix strategy was to determine how e-waste plastic and glass fibre addition affected mechanical strength, density and water absorption. All mixtures were prepared at a uniform water-to-gypsum (W/G) ratio to limit the effect of changing water content. The W/G ratio was selected from preliminary work and held constant throughout the experimental series. Table 4 reports nominal percentages; the available records did not establish whether these are mass or volume fractions.

2.6 Mixing Procedure and Sample Preparation

The gypsum-based composites were prepared by dry and wet mixing, followed by casting, rod compaction, demoulding and chamber curing. The recorded operational settings are reported below.

2.6.1 Step 1: Material Preparation

The raw materials, i.e., powdered gypsum, shredded e-waste plastic, cut pieces of glass fibre strands, and clean drinkable water, were put together in weight and measurements. The e-waste plastic was pre-processed by cleaning, drying, and shredding into fine, uniformly sized flakes (approximately 2–5 mm), while the glass fibre was chopped into strands with lengths of approximately 6–12 mm to ensure uniform dispersion and effective reinforcement.

Table 4 Nominal mixture proportions (mass or volume basis not recorded)

Sample ID	Gypsum (%)	E-Waste Plastic (%)	Glass fibre (%)	Reason for This Mix
A (Control)	100	0	0	Baseline for comparison with all modified mixtures.
B	90	10	0	Isolates the reported response of 10% e-waste plastic without glass fibre.
C	85	10	5	Examines 5% glass fibre at the same 10% e-waste plastic proportion as Sample B.
D	80	15	5	Examines a higher e-waste plastic proportion (15%) with 5% glass fibre.
E	75	15	10	Examines 15% e-waste plastic with the highest glass-fibre proportion (10%).

2.6.2 Step 2: Dry Mixing

The gypsum powder and the e-waste plastic were dry-mixed in a clean, non-reactive container for approximately 2–3 min to distribute the solid components. The dry-mixing speed was not recorded. This step was used to disperse the plastic particles while limiting agglomeration of the glass fibre.

2.6.3 Step 3: Water Addition and Wet Mixing

After dry blending, the pre-determined water quantity was added gradually at a water-to-gypsum ratio of 0.21 by mass. Wet mixing was performed mechanically at approximately 200 rpm for approximately 2 min, followed by approximately 400–500 rpm for a further 3–5 min to obtain a uniform paste. These settings were approximate operational values rather than continuously logged measurements.

2.6.4 Step 4: Casting and Moulding

The mixture was cast immediately into moulds appropriate to each reported mechanical test: 40 mm × 40 mm × 160 mm prisms for flexural testing and 50 mm × 50 mm × 50 mm cubes for compressive testing. Each mould was filled in two layers, and each layer was compacted with a tamper rod to reduce entrained air.

2.6.5 Step 5: Curing

The filled moulds were covered with plastic sheet and kept for approximately 24 h at an ambient temperature of approximately 25 ± 2 °C to limit moisture loss. Specimens were demoulded after this approximately 24 h period and transferred to a curing chamber maintained at approximately 23–25 °C and approximately 95% relative humidity. Curing periods of 7 and 28 days were used, but the strength results reported in Tables 5 and 6 are the 28-day values. The stated temperature and humidity values are approximate ranges.

**Fig. 3** Moulds undergoing curing period

2.6.6 Step 6: Sample Identification

Each specimen was assigned an appropriate sample ID (A-E), date of casting, and testing schedule to provide traceability and consistency from casting through the testing phases.

2.7 Testing Procedures

Mechanical performance was evaluated through compressive- and flexural-strength testing using the procedures described below. The tests assessed the loading capacity and the reinforcement response associated with the e-waste plastic and glass fibre additions.

2.7.1 Compressive Strength Test

Compressive strength testing was conducted with reference to ASTM C109/C109M - Standard Test Method for Compressive Strength of Hydraulic Cement Mortars, using 50 mm × 50 mm × 50 mm cube specimens.

Cubic specimens measuring 50 mm × 50 mm × 50 mm were used. Three specimens were tested for each mix proportion (A-E). This small replicate set is used for descriptive comparison only and is not presented as statistically sufficient for population-level inference.

2.7.2 Flexural Strength Test

Flexural strength was evaluated to determine the resistance of the composite materials to bending, following ASTM C348 - *Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars*. Rectangular prism specimens measuring 40 mm × 40 mm × 160 mm were cast for each mix. Three specimens per mix were tested after the curing period. As with compressive testing, these replicates support descriptive summaries only. No Shapiro-Wilk normality test, Levene's homogeneity-of-variance test or ANOVA was performed for either strength dataset. The reported means and standard deviations are therefore descriptive; observed differences between formulations are not claims of statistical significance and require confirmation with a larger replicate set.

2.7.3 Finite Element Modeling Protocol

Exploratory FEA was conducted in ANSYS Mechanical for three numerical material definitions: FEA-A (pure gypsum), FEA-B (5% plastic) and FEA-C (10% plastic). These FEA identifiers are separate from the experimental A-E formulation IDs in Table 4.

- **Geometry & Element Type:** For each FEA material definition, model "1" used a 50 mm × 50 mm × 50 mm cube and model "2" used a 40 mm × 40 mm × 160 mm prism. The solved reports record program-controlled element formulation.
- **Material Mapping:** Each body was represented as a homogeneous, linear isotropic material using the values recorded in the solved reports. The reported Young's modulus/Poisson's ratio pairs were 10,000 MPa/0.28 for FEA-A, 9,200 MPa/0.29 for FEA-B, and 9,800 MPa/0.28 for FEA-C. The models did not represent plastic particles or glass fibres as separate phases.
- **Boundary Conditions & Loading:** The "1" cube models used one fixed face and a ramped Y-displacement to -0.5 mm on the opposite face. The "2" prism models used fixed support on 16 element faces and a surface force ramped from 100 N to 500 N over five load steps.
- **Mesh:** FEA-A1 to FEA-C1 used a 2.0 mm element size (68,276 nodes and 15,625 elements); FEA-A2 to FEA-C2 used a 5.0 mm element size (10,017 nodes and 2,048 elements). The supplied reports do not document a mesh-independence study, so the results are interpreted descriptively.
- **Interpretive Boundary:** The cube and prism cases used different loading modes, and the FEA material definitions were not mapped one-to-one to the experimental mixtures in Table 4. The FEA results are therefore not presented as failure-load predictions or quantitative validation of the experimental data.

3. Results and Discussion

This paper presents the experimental results and analysis of the e-waste plastic and glass fibre reinforced gypsum-based composites. The reported properties are compressive strength, flexural strength, bulk density and water absorption. The compressive and flexural tests followed the cited ASTM methods; the density and water-absorption values are reported descriptively.

3.1 Compressive Strength

After the 28-day curing period, compressive strength was measured using 50 mm × 50 mm × 50 mm cube specimens. The mean compressive strength for each mix was calculated from three replicate results, as shown in

Table 5. Values are reported in megapascals (MPa). The means and standard deviations are interpreted descriptively, without inferential comparison.

Table 5 Descriptive compressive-strength results ($n = 3$ per formulation)

Sample	Rep-1 (MPa)	Rep-2 (MPa)	Rep-3 (MPa)	Mean (MPa)	SD (MPa)
A (100% Gypsum)	24.8	25.2	24.5	24.8	0.35
B (90% Gypsum, 10% e-waste plastic)	22.1	21.9	22.4	22.1	0.25
C (85% Gypsum, 10% e-waste plastic, 5% GF)	28.5	29.0	28.3	28.6	0.36
D (80% Gypsum, 15% e-waste plastic, 5% GF)	26.4	26.1	25.9	26.1	0.25
E (75% Gypsum, 15% e-waste plastic, 10% GF)	33.2	32.8	33.0	33.0	0.20

As seen, the addition of e-waste plastic and glass fibre material has a great effect on the compressive strength. The mean strength of the control sample (A) was 24.8 MPa. The 10% e-waste plastic (Sample B) further decreased the compressive strength to 22.1 MPa, which suggested that the strength of the gypsum matrix was decreased due to plastic inclusion and as a result, a reduction in cementitious bonding was observed. The strength was raised to 28.6 MPa when 5% glass fibre was used in addition to 10% e-waste plastic (Sample C) because the fibres could bridge and transfer the crack. The hybrid material sample E (composed of 15% e-waste plastic and 10% glass fibre) yielded the highest observed mean strength of 33.0 MPa, which is around 33% higher than that of the control sample, giving the best observed result among the tested mixtures.

3.2 Flexural Strength

Flexural strength was evaluated on $40 \times 40 \times 160$ mm prisms after 28 days of curing using three-point bending tests. The results are summarized in Table 6. The flexural test results were similar to the compressive strength results. The control sample had a flexural strength of 6.6 MPa. When adding e-waste plastic only (Sample B), it was slightly decreased to 5.8 MPa as a result of the low bonding force between the plastic and gypsum. When glass fibre was added (Samples C and E), however, the flexural strength rose quite dramatically, to 8.9 MPa and 10.8 MPa respectively. The Sample E mean is approximately 64% higher than the control mean; this is a descriptive difference and not evidence of statistical significance.

Table 6 Descriptive flexural-strength results ($n = 3$ per formulation)

Sample	Rep-1 (MPa)	Rep-2 (MPa)	Rep-3 (MPa)	Mean (MPa)	SD (MPa)
A (Control)	6.5	6.8	6.4	6.6	0.21
B	5.8	6.0	5.7	5.8	0.15
C	8.9	9.1	8.8	8.9	0.15
D	7.2	7.5	7.0	7.2	0.25
E	10.8	11.0	10.7	10.8	0.15

3.3 Density and Water Absorption

Bulk density and water absorption tests were performed to evaluate the effect of e-waste plastic and glass fibre on physical properties of the composites. The results can be seen in Table 7. The reported density decreased from 2400 kg/m^3 for the control sample to 1950 kg/m^3 for Sample E, representing a reduction of approximately 19%. This decrease was associated with partial replacement of gypsum by the e-waste plastic fraction and voids formed during fibre dispersion. Water absorption was lower than the control value for every modified mixture, although the sequence was not monotonic: Sample D (9.2%) was higher than Sample C (8.5%). Sample E had the lowest reported water absorption at 7.5%.

Table 7 Density and water absorption

Sample	Density (kg/m ³)	Water Absorption (%)
A	2400	11.5
B	2250	9.8
C	2200	8.5
D	2100	9.2
E	1950	7.5

3.4 Scope and Summary of Numerical Results

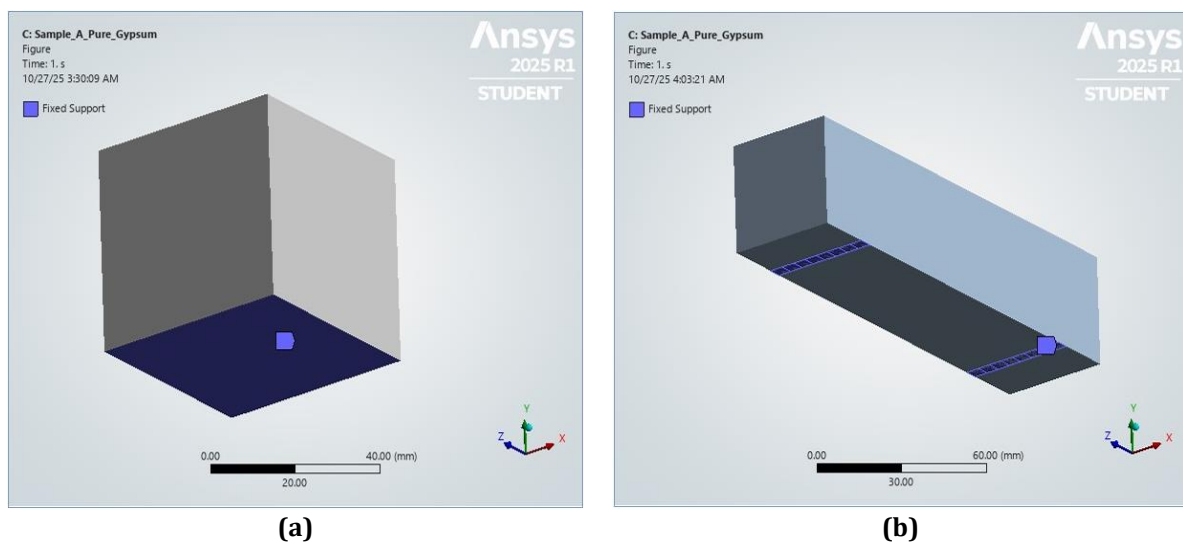
Table 8 summarises selected end-step outputs from the solved FEA-A to FEA-C reports. The numerical model set is described separately from the experimental results because its identifiers, formulations and loading modes are not directly equivalent.

Table 8 Selected end-step ANSYS results for the reported FEA-A to FEA-C models

FEA model / solved-report definition	End-step maximum total deformation; maximum equivalent stress
FEA-A1 cube / FEA-A2 prism (pure gypsum)	A1: 0.51055 mm; 267.51 MPa. A2: 0.0027553 mm; 1.3142 MPa
FEA-B1 cube / FEA-B2 prism (5% plastic)	B1: 0.51136 mm; 252.13 MPa. B2: 0.002989 mm; 1.3135 MPa
FEA-C1 cube / FEA-C2 prism (10% plastic)	C1: 0.51055 mm; 262.16 MPa. C2: 0.0028115 mm; 1.3142 MPa
Interpretive boundary	Cube cases were displacement-controlled; prism cases were force-controlled. These outputs are not strength predictions or experimental validation

3.4.1 FEA-A1 and FEA-A2 – Pure Gypsum

The fixed-support conditions for pure-gypsum models FEA-A1 and FEA-A2 are shown in Fig. 4. The prescribed displacement condition for FEA-A1 is shown in Fig. 5. Graphs and contours of total deformation are shown in Fig. 6 and Fig. 7. Equivalent-stress graphs and contours are shown in Fig. 8 and Fig. 9, with tabulated values in Table 9 and Table 10. Equivalent-elastic-strain graphs and contours are shown in Fig. 10 and Fig. 11. Force-reaction graphs and vector displays are shown in Figs. 12 and 13.

**Fig. 4** Fixed-support conditions for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

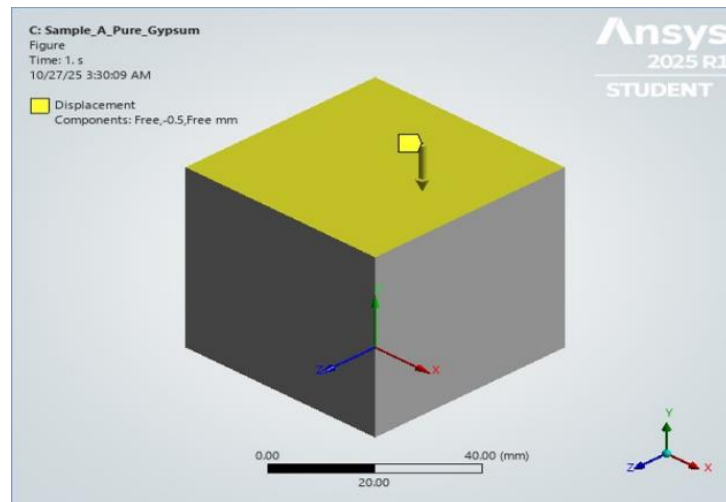
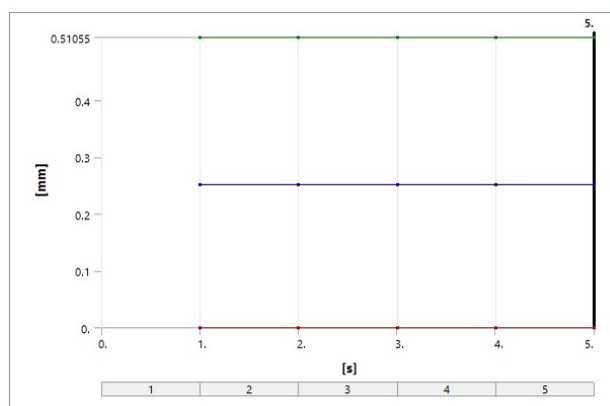
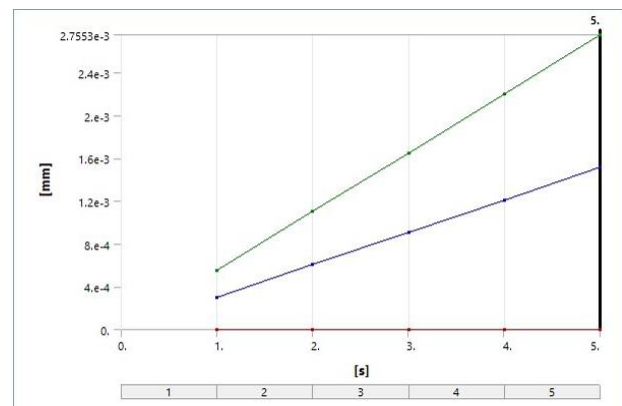


Fig. 5 Prescribed displacement condition for pure-gypsum model FEA-A1

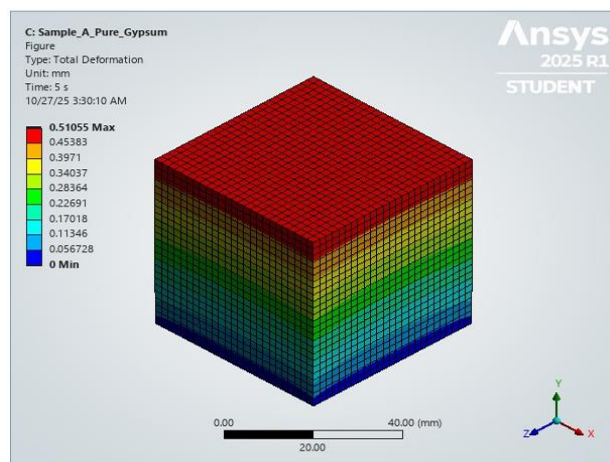


(a)

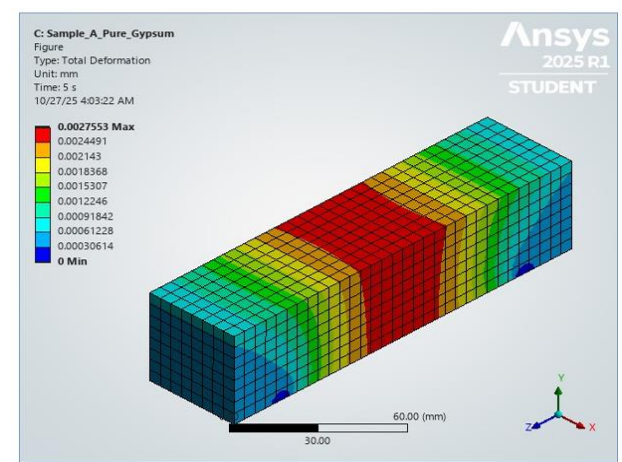


(b)

Fig. 6 Total-deformation graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2



(a)



(b)

Fig. 7 Total-deformation graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

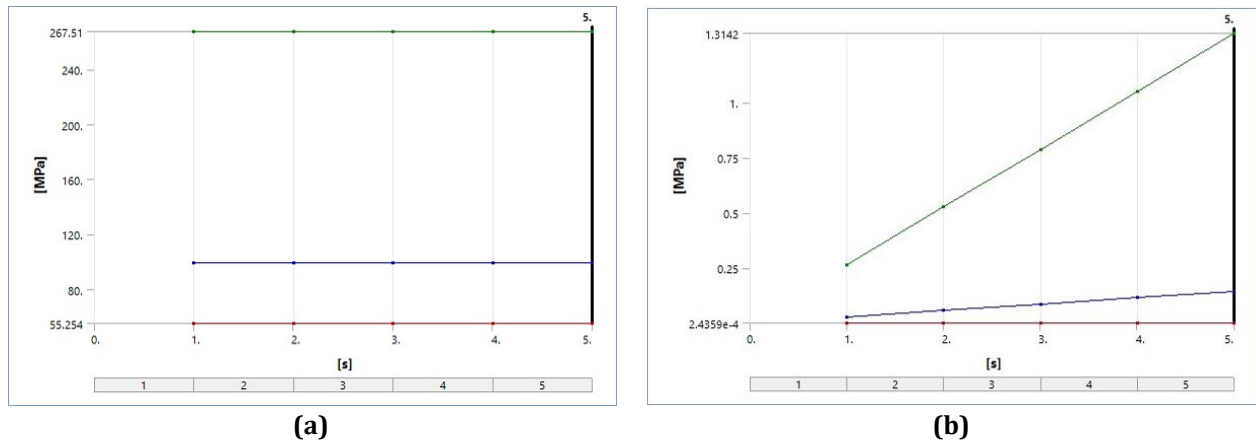


Fig. 8 Equivalent-stress graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

Table 9 Equivalent-stress results for pure-gypsum model FEA-A1

Time (s)	Minimum (MPa)	Maximum (MPa)	Average (MPa)
1	55.254	267.47	99.013
2	55.257	267.51	99.013
3	55.257	267.51	99.013
4	55.257	267.51	99.013
5	55.257	267.51	99.013

Table 10 Equivalent-stress results for pure-gypsum model FEA-A2

Time (s)	Minimum (MPa)	Maximum (MPa)	Average (MPa)
1	2.4359e-004	0.26283	2.877e-002
2	4.8718e-004	0.52567	5.7541e-002
3	7.3077e-004	0.7885	8.6312e-002
4	9.7435e-004	1.0513	0.11508
5	1.2179e-003	1.3142	0.14386

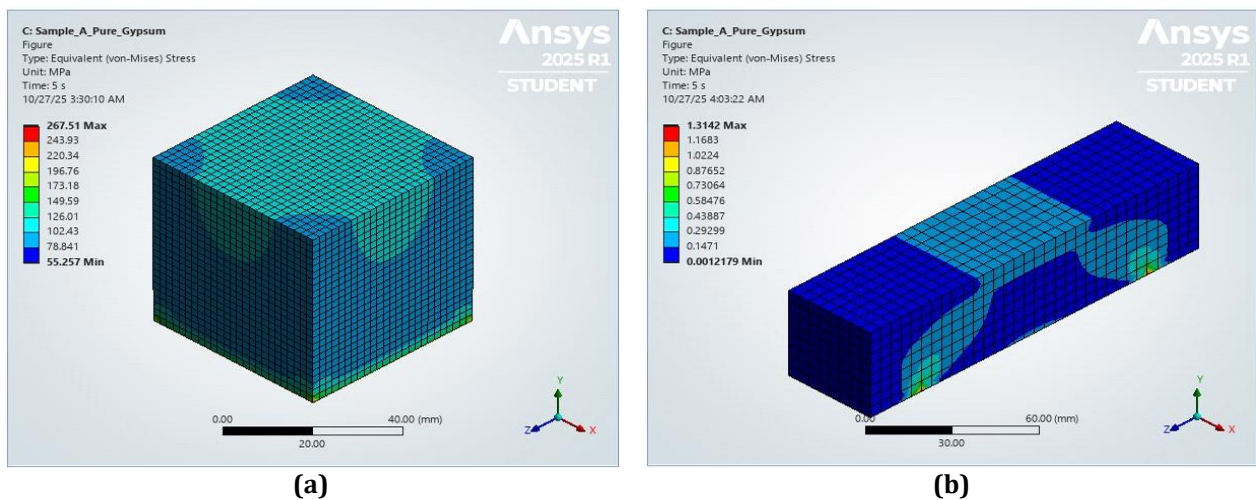


Fig. 9 Equivalent-stress contours for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

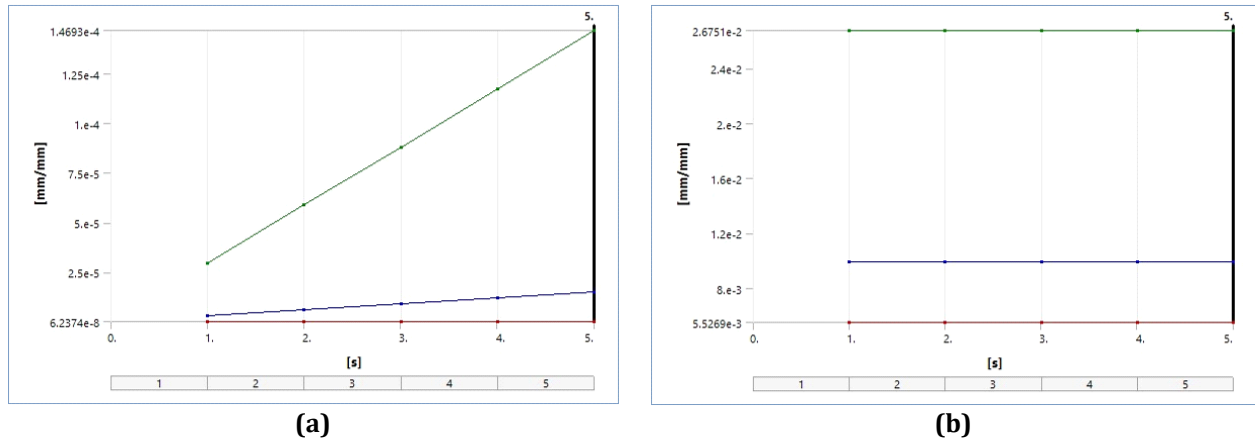


Fig. 10 Equivalent-elastic-strain graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

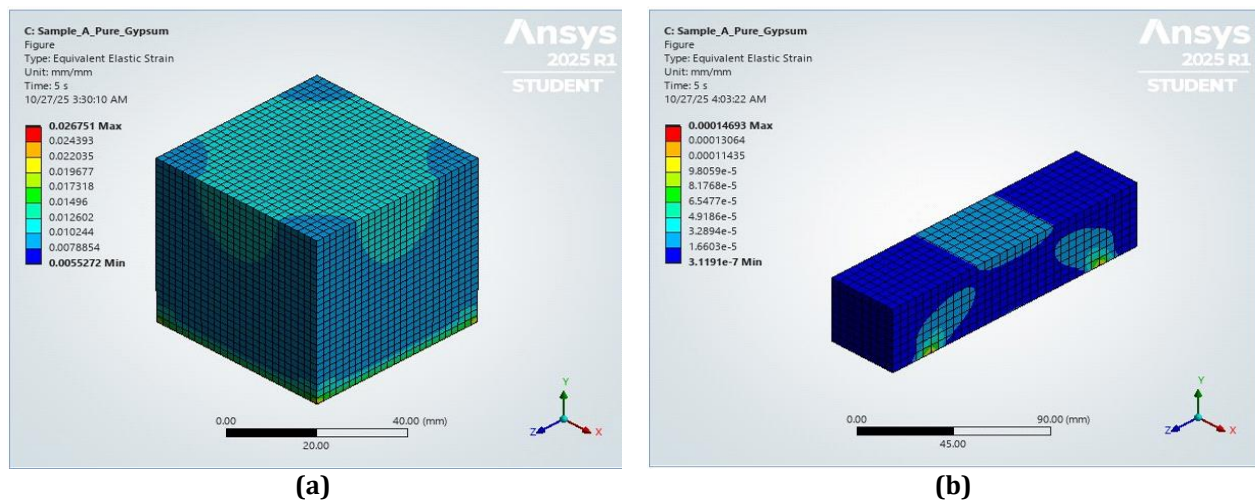


Fig. 11 Equivalent-elastic-strain graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

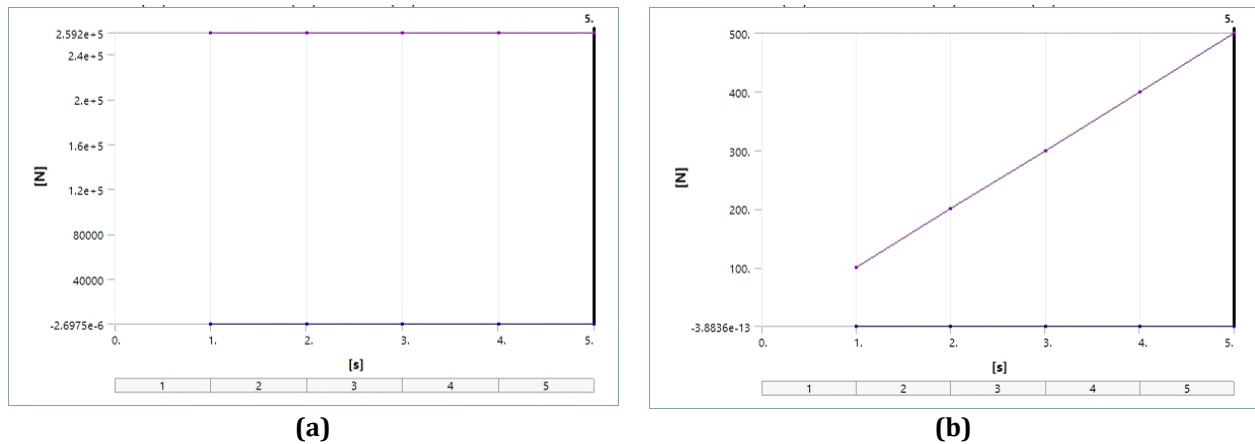


Fig. 12 Force-reaction graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

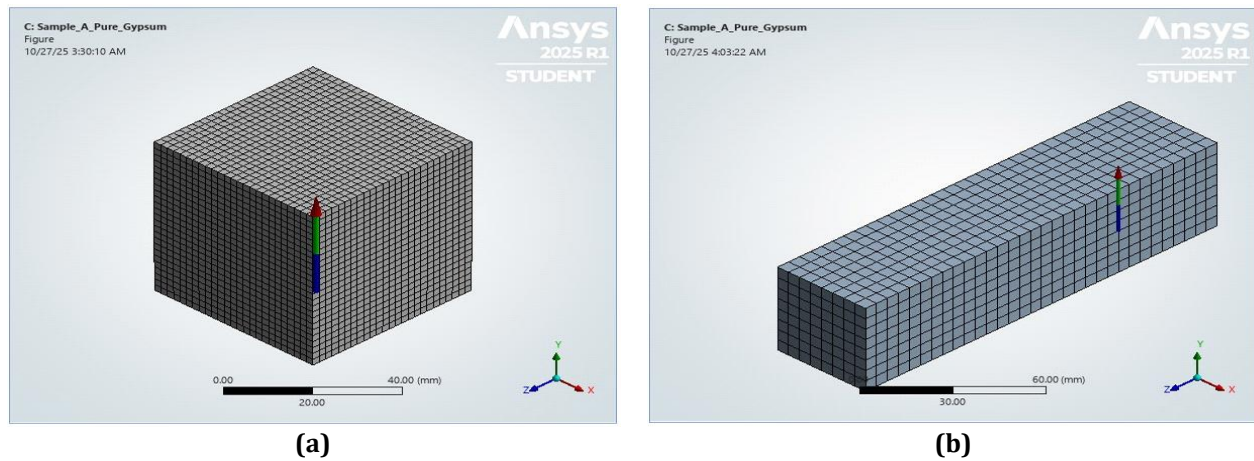


Fig. 13 Force-reaction graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

3.4.2 FEA-B1 and FEA-B2 – 5% E-Waste Plastic

Fixed-support conditions for FEA-B1 and FEA-B2 are shown in Fig. 14. The applied loading histories—prescribed displacement for FEA-B1 and force for FEA-B2—are shown in Fig. 15. Total-deformation contours are shown in Fig. 16. Equivalent-elastic-strain graphs and contours are shown in Fig. 17 and Fig. 18. Equivalent-stress graphs and contours are shown in Fig. 19 and Fig. 20. Force-reaction graphs and vector displays are shown in Fig. 21 and Fig. 22.

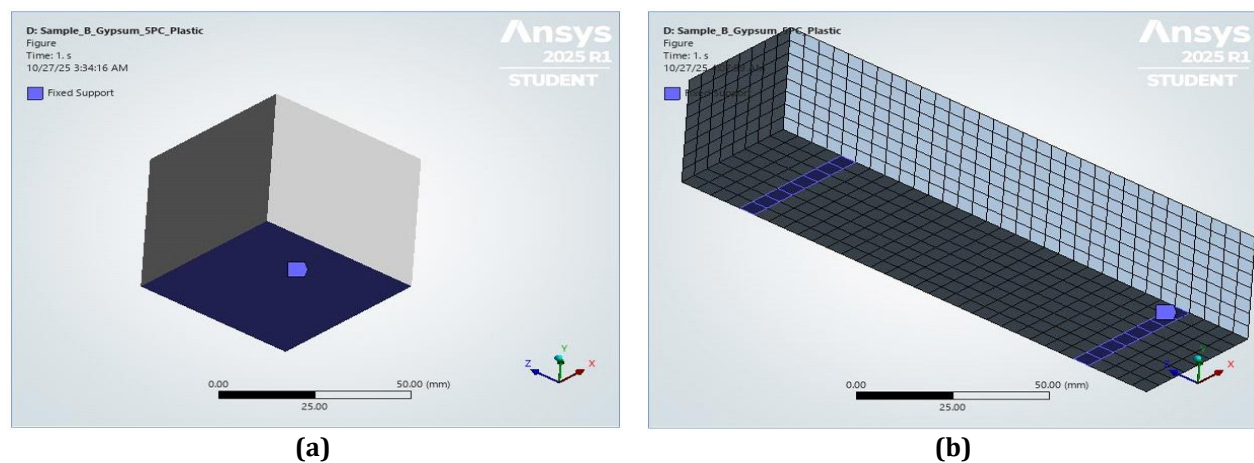


Fig. 14 Force-reaction graphs for pure-gypsum models (a) FEA-A1; and (b) FEA-A2

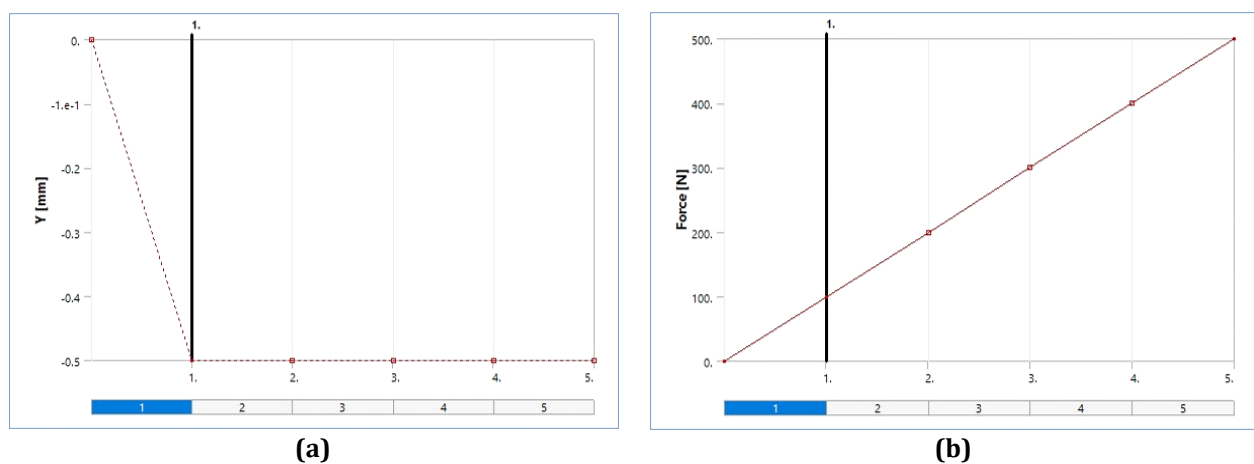
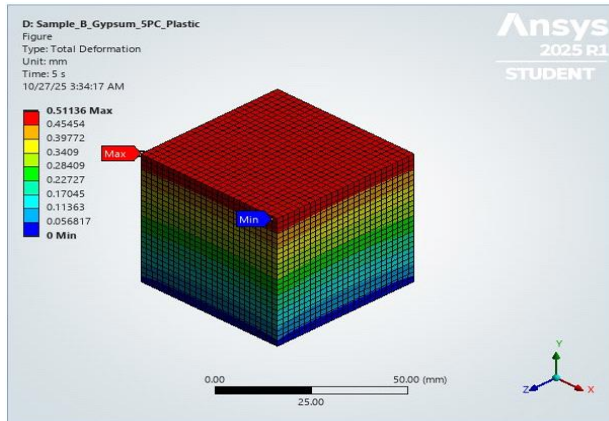
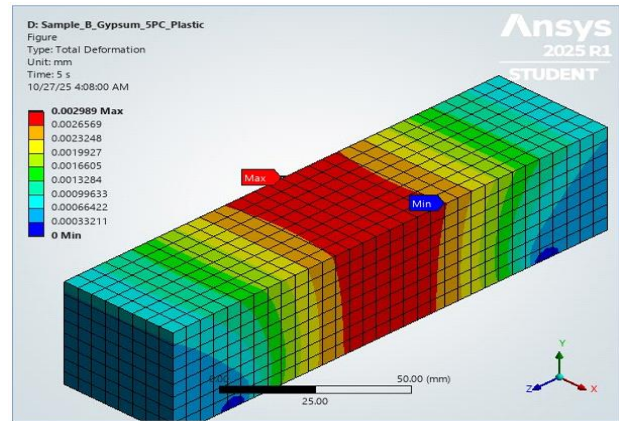


Fig. 15 Applied loading histories: prescribed displacement for (a) FEA-B1; and force for (b) FEA-B2

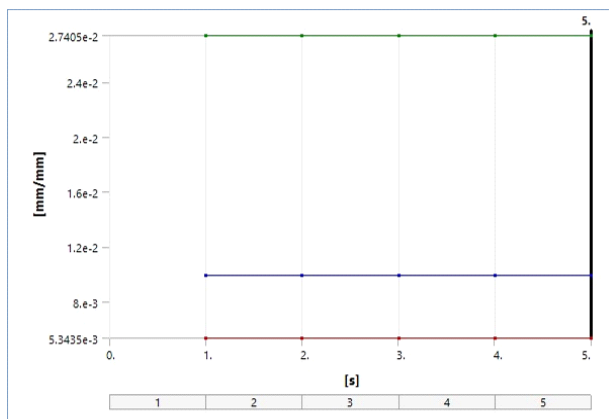


(a)

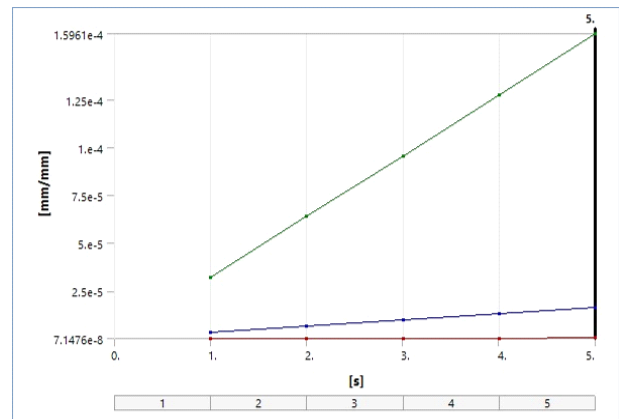


(b)

Fig. 16 Total-deformation contours for models (a) FEA-B1; and (b) FEA-B2

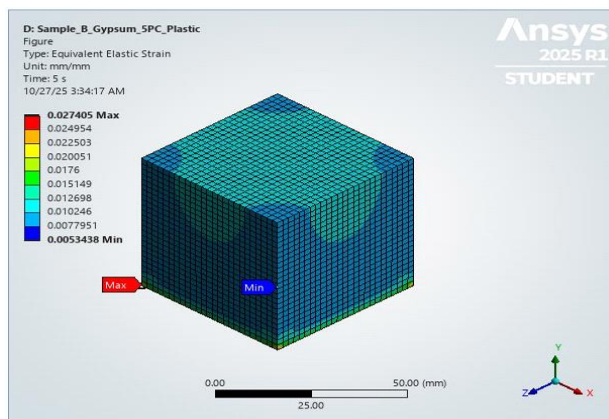


(a)

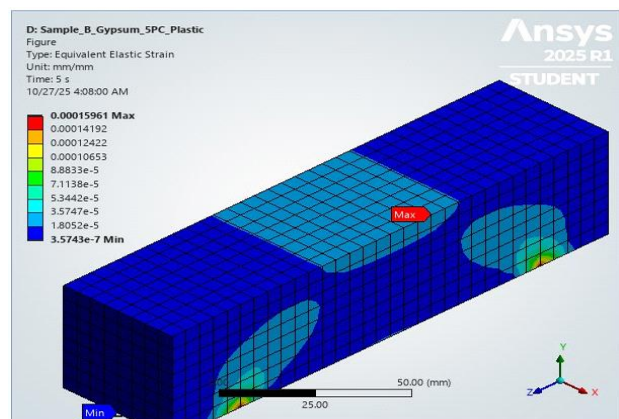


(b)

Fig. 17 Equivalent-elastic-strain graphs for models (a) FEA-B1; and (b) FEA-B2



(a)



(b)

Fig. 18 Equivalent-elastic-strain graphs for models (a) FEA-B1; and (b) FEA-B2

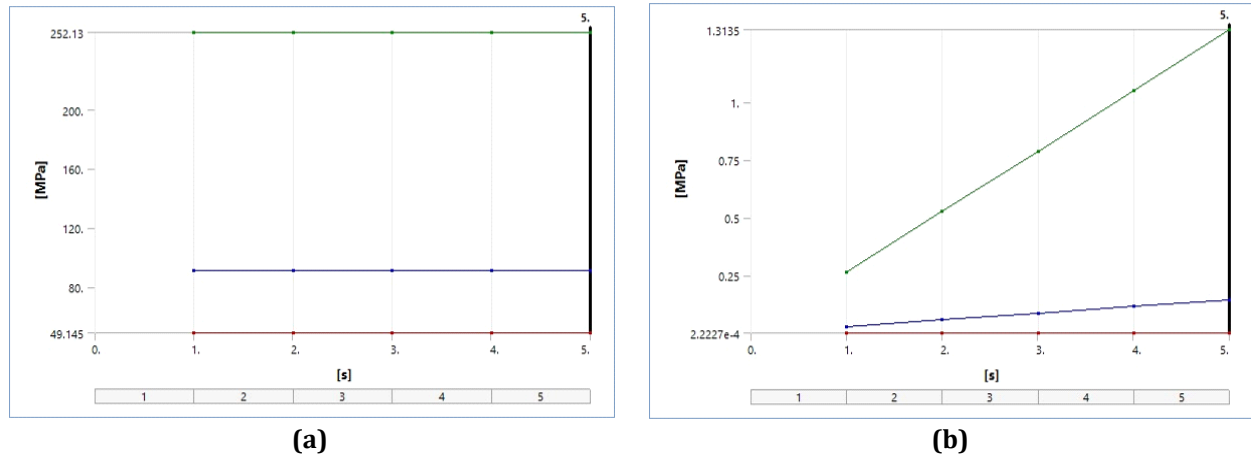


Fig. 19 Equivalent-stress graphs for models (a) FEA-B1; and (b) FEA-B2

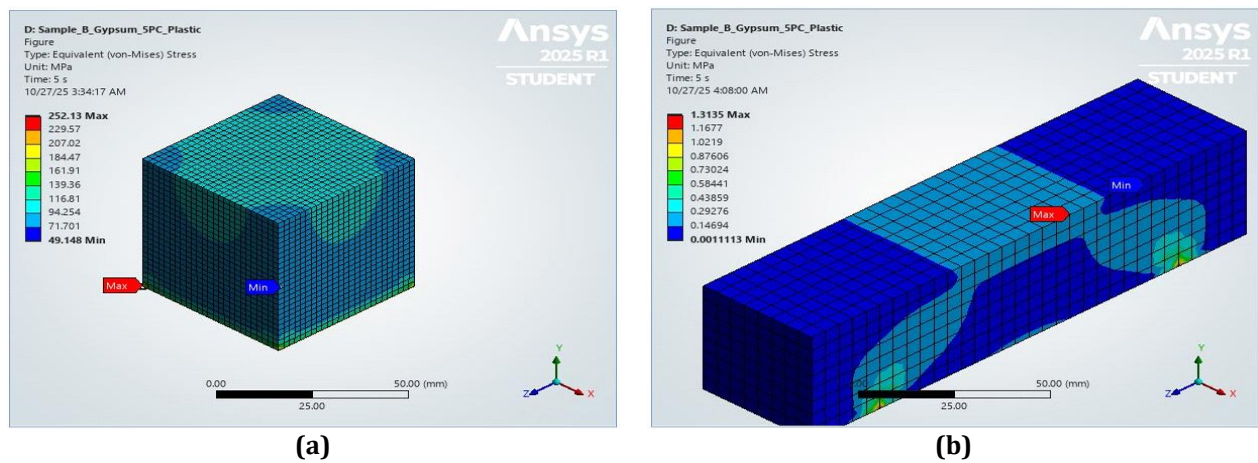


Fig. 20 Equivalent-stress contours for models (a) FEA-B1; and (b) FEA-B2

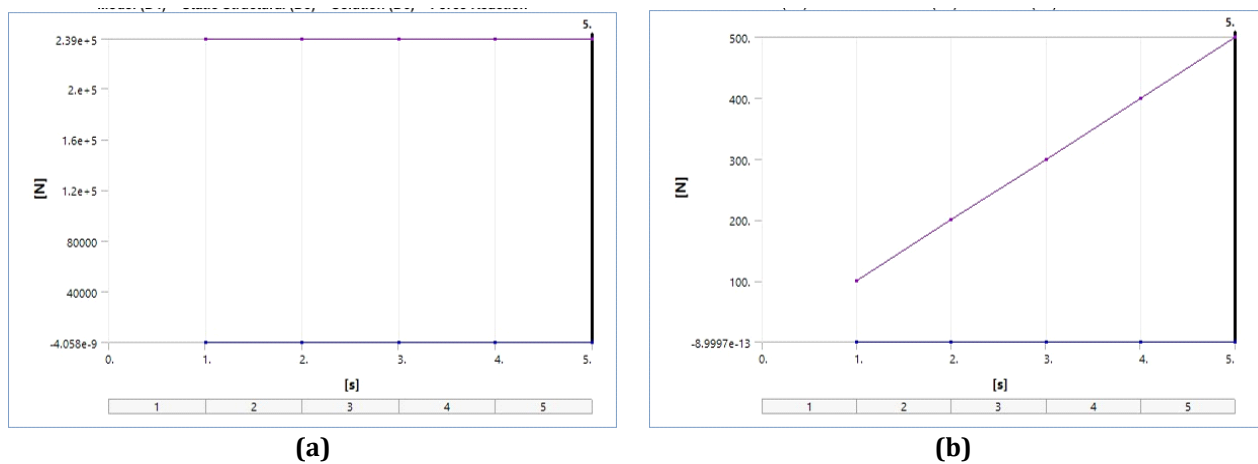


Fig. 21 Force-reaction graphs for models (a) FEA-B1; and (b) FEA-B2

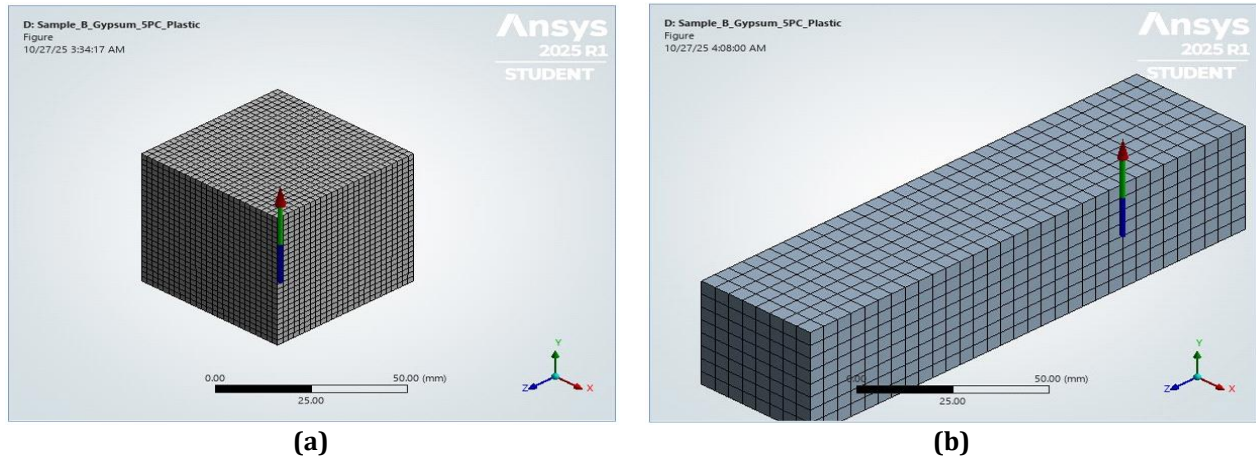


Fig. 22 Force-reaction vector displays for models (a) FEA-B1; and (b) FEA-B2

3.4.3 FEA-C1 and FEA-C2 – 10% E-Waste Plastic

Total-deformation graphs and contours for FEA-C1 and FEA-C2 are shown in Fig. 23 and Fig. 24. Equivalent-elastic-strain graphs and contours are shown in Fig. 25 and Fig. 26. Equivalent-stress graphs and contours are shown in Fig. 27 and Fig. 28. Force-reaction graphs and vector displays are shown in Fig. 29 and Fig. 30.

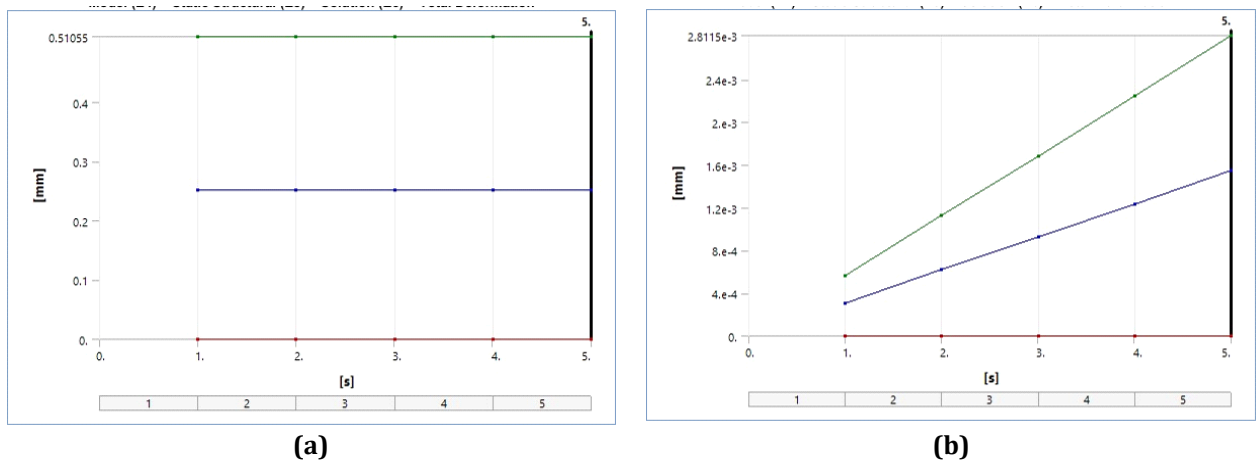


Fig. 23 Total-deformation graphs for models FEA-C1 and FEA-C2 (10% e-waste plastic)

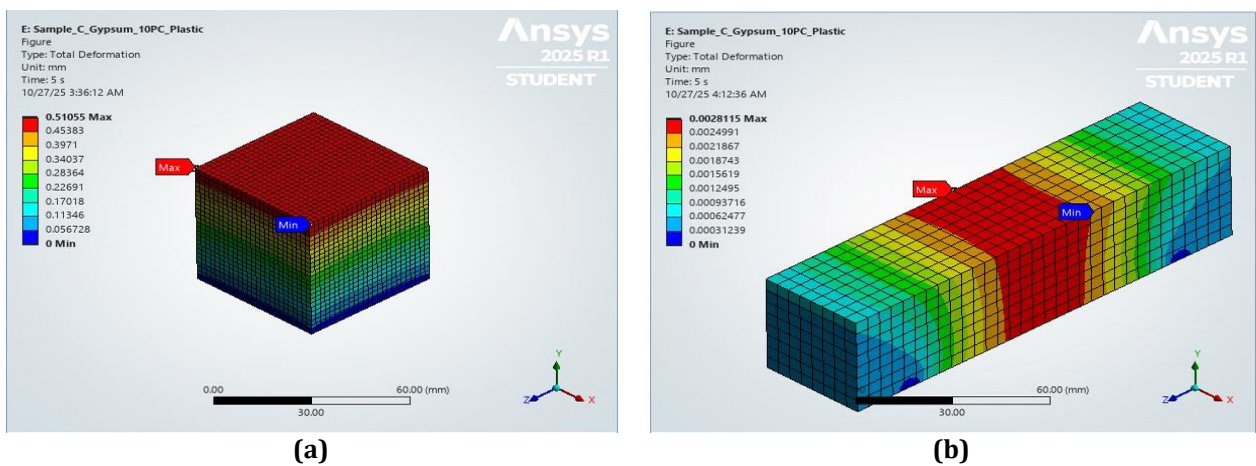


Fig. 24 Total-deformation contours for models (a) FEA-C1; and (b) FEA-C2

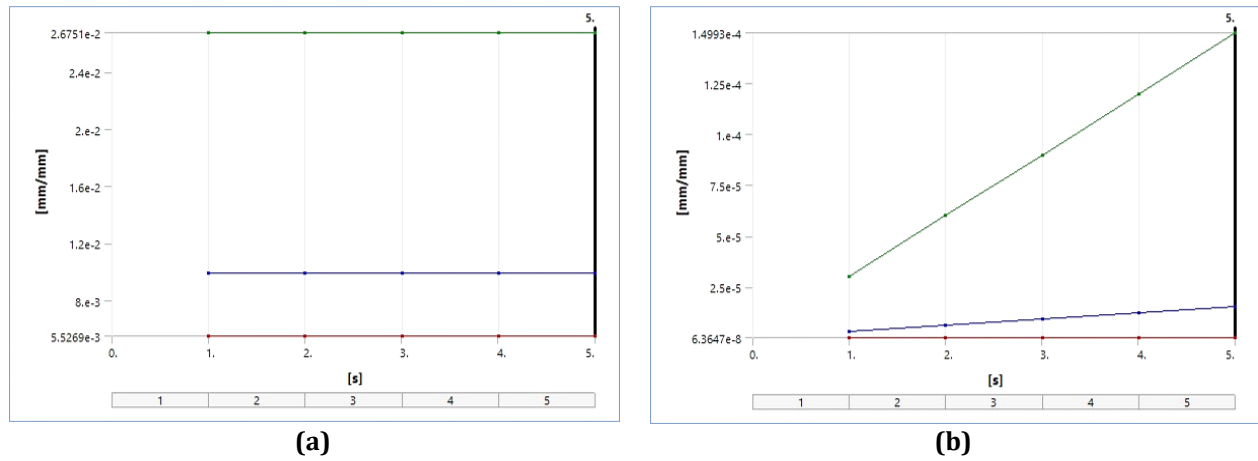


Fig. 25 Equivalent-elastic-strain graphs for models (a) FEA-C1; and (b) FEA-C2

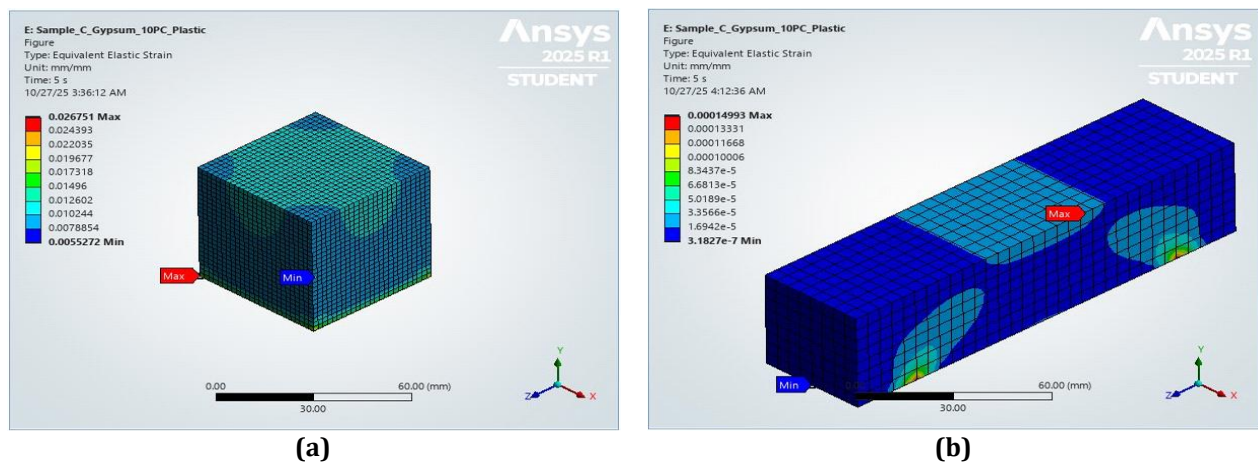


Fig. 26 Equivalent-elastic-strain contours for models (a) FEA-C1; and (b) FEA-C2

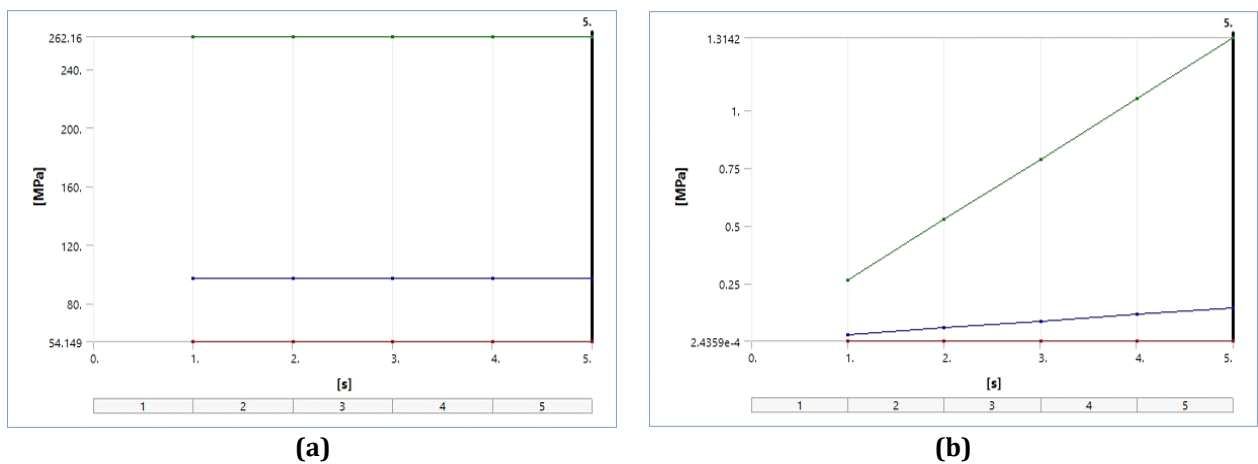


Fig. 27 Equivalent-stress graphs for models (a) FEA-C1; and (b) FEA-C2

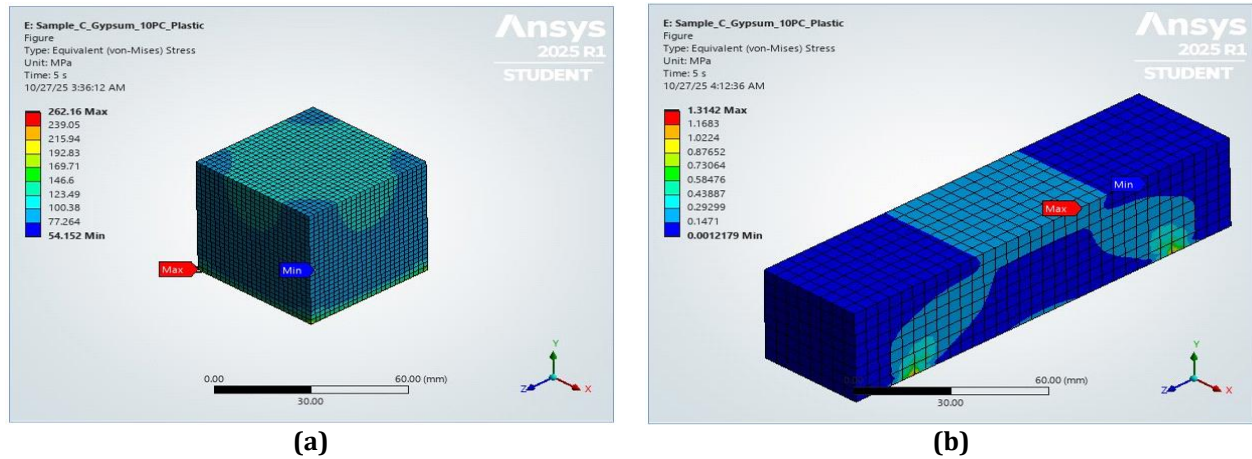


Fig. 28 Equivalent-stress contours for models (a) FEA-C1; and (b) FEA-C2

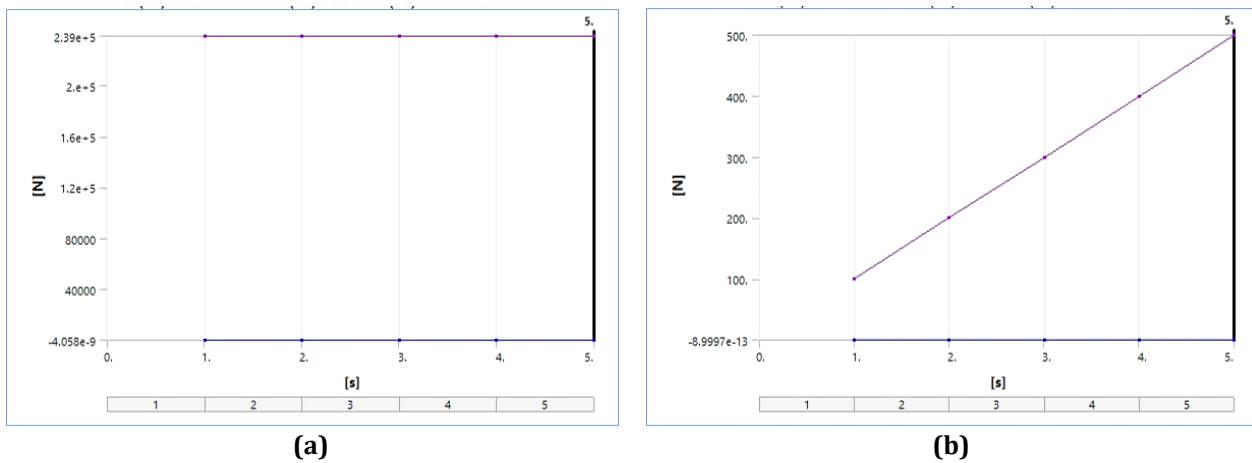


Fig. 29 Force-reaction graphs for models (a) FEA-C1; and (b) FEA-C2

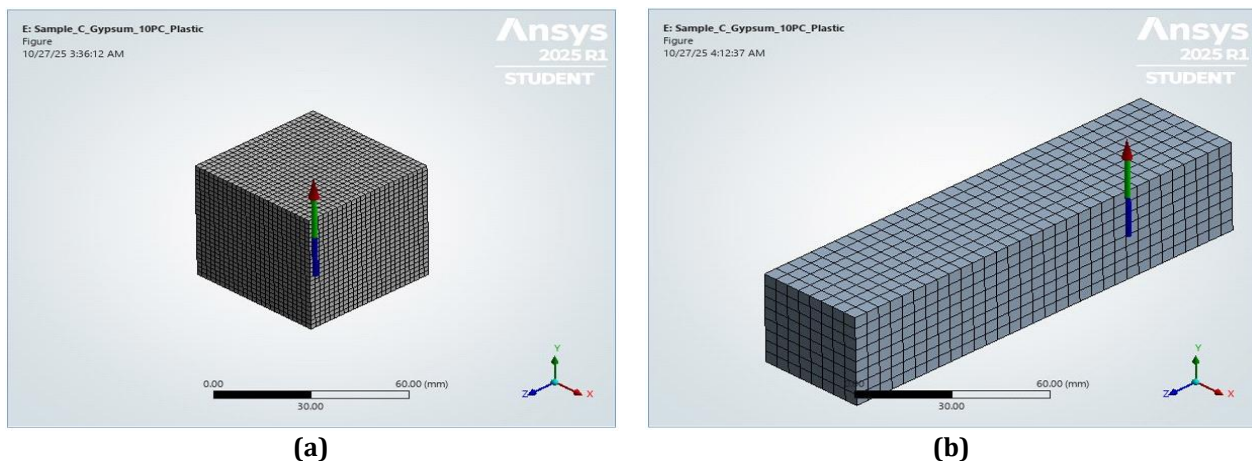


Fig. 30 Force-reaction vector displays for models (a) FEA-C1; and (b) FEA-C2

3.5 Discussion of ANSYS Simulation

Fig. 4 to Fig. 30 show the solved field outputs for the separate FEA-A to FEA-C models. The “1” cube models were displacement-controlled, whereas the “2” prism models were force-controlled. Consequently, cube and prism magnitudes should not be compared as if they arose from the same test, and the results are interpreted within each load case.

3.5.1 Mesh and Model Scope

The FEA-A1 to FEA-C1 cube reports record a 2.0 mm element size, 68,276 nodes and 15,625 elements; the FEA-A2 to FEA-C2 prism reports record a 5.0 mm element size, 10,017 nodes and 2,048 elements. The analyses use homogeneous material bodies, so they do not resolve the gypsum–plastic or gypsum–glass interfaces discussed in heterogeneous-material literature [17–20]. No mesh-independence result is reported in the supplied files.

3.5.2 Equivalent-Stress

At the final load step, maximum equivalent stress in the displacement-controlled cube models was 267.51 MPa for FEA-A1, 252.13 MPa for FEA-B1 and 262.16 MPa for FEA-C1. In the 500 N prism models, the corresponding maxima were 1.3142, 1.3135 and 1.3142 MPa. The near-identical prism stresses reflect their common geometry and applied force. Although the contour pattern is consistent with bending stress localisation [21–23], the linear homogeneous models do not simulate crack initiation, crack bridging or failure.

3.5.3 Total Deformation

The maximum total deformation of the cube models remained close to the prescribed 0.5 mm displacement: 0.51055 mm (FEA-A1), 0.51136 mm (FEA-B1) and 0.51055 mm (FEA-C1). Under the common 500 N prism load, maximum total deformation was 0.0027553 mm (FEA-A2), 0.002989 mm (FEA-B2) and 0.0028115 mm (FEA-C2). These values describe the response of the assigned homogeneous properties and boundary conditions; they do not by themselves establish improved load-carrying capacity or product performance [24,25].

3.5.4 Interpretive Limits

Literature reports that glass-fibre reinforcement can improve bond behaviour, energy absorption and failure resistance in gypsum and other composite systems [26–28]. However, the detailed models shown in Fig. 4 to Fig. 30 comprise pure-gypsum and plastic-containing FEA-A to FEA-C definitions and do not explicitly model glass fibres. The displayed simulations therefore cannot be used to infer fibre bridging or fibre–matrix strain compatibility.

The ANSYS results are retained as an exploratory visualisation of stress, strain and deformation under the stated idealised conditions. They do not establish durability, safety under building service loads or quantitative agreement with the experimental strength data. Those conclusions would require aligned material definitions, matched test boundary conditions, failure criteria, and mesh-convergence and validation studies.

4. System-Level Implications for Resource Recovery

4.1 Extending Resource Recovery Beyond Metals

In this experimental work, e-waste plastic fractions that typically remain underutilised in informal recycling systems were evaluated as ingredients in gypsum-based composites. Their effects were formulation-dependent, as shown by the measured mechanical and physical properties in Table 5 to Table 7.

This aligns with emerging research that highlights the need for expanding resource recovery beyond metals to plastics and other non-metallic waste fractions [2,10]. Such extensions can lead to enhanced overall recovery efficiency and reduced environmental leakage of e-waste polymers.

4.2 Decentralised Production and Informal Sector Integration

Conventional recycling programmes are dependent on large buildings, investments and formalised regulations in target facilities, these features are lacking in many parts of Nigeria, and even more in similar environments [3]. The composite manufacturing methodology developed here; shredding, dry mixing, adding water and casting, can be realized with the help of moderately sized equipment, which enables the implementation of small manufacturing units or community machine-shops to produce composites. Decentralized models could connect with the informal waste collectors and processors as well, to offer better livelihood opportunities and material recovery.

4.3 Resource Efficiency, Circularity and Screening Environmental Estimates

Incorporation of e waste polymers into the manufacture of building materials contributes to resource efficiency by converting underutilised waste streams into value added products. This approach reduces the reliance on virgin gypsum and other resource-intensive materials, reduces the pressures of waste disposal and is consistent with circular economy principles that prioritise waste as an input resource rather than an environmental burden

[9]. The lower density and water absorption of plastic reinforced composites also suggest potential secondary benefits such as thermal insulation properties which warrant further investigation.

A conditional screening mass-balance was prepared for mixture E using a functional unit of 1 m³. If the nominal 15% plastic proportion in Table 4 is interpreted as a dry-mass fraction, applying the reported composite density of 1950 kg/m³ gives $0.15 \times 1950 = 292.5$ kg/m³, rounded to approximately 290 kg of post-consumer e-waste plastic per cubic metre of composite. This is an illustrative calculation rather than a measured plastic-content result because the proportion basis was not independently documented.

The conditional 290 kg/m³ value is a material-incorporation estimate rather than a measured landfill-diversion total. The counterfactual waste-management route was not monitored, and uncertainty in the mixture basis and reported density was not quantified.

A quantitative embodied-carbon reduction cannot be verified from the reported data because the study did not inventory collection and transport, shredding electricity, purchased-glass-fibre production, service life or end-of-life. The gypsum calcination range cited in [13] is insufficient on its own to calculate a percentage reduction. A complete life-cycle assessment is therefore identified as future work.

4.4 Challenges, International Benchmarks and Enablers for Adoption

While it is technically feasible, the usage of e-waste made gypsum composites should benefit from supportive policy and regulatory support, standardisation and control of materials to scale the use of the composites. A standard for building materials utilising recycled content is not existent in Nigeria which makes it hard for the uptake into the formal construction sector. To promote the circular use of materials, there is a need to establish acceptable performance thresholds, certification procedures and financial incentives that stakeholders, industry and regulators can agree upon.

Beyond the Nigerian context, international adoption would require product-level conformity with the standards applicable in the target market. ASTM C1396/C1396M-24 specifies gypsum-board products used for walls, ceilings and partitions [29], while EN 13279-1:2008 defines requirements and conformity provisions for gypsum binders and plasters, including binders intended for further processing into fibrous-reinforced gypsum boards and ceiling elements [30]. The reported density of 1950 kg/m³ and mean flexural strength of 10.8 MPa for mixture E provide preliminary screening values, but the specimen-level tests used in this study do not establish compliance with either product standard. Full-size product geometry, reaction to fire, impact performance, dimensional tolerances, durability, hazardous-substance control and conformity assessment were not evaluated.

At the regulatory level, Article 6 of the EU Waste Framework Directive requires a recovered material to have a specific use and market, satisfy applicable technical and product requirements, and avoid overall adverse environmental or human-health impacts before end-of-waste status can be established [31]. The present results therefore support a research pathway rather than an end-of-waste or certification claim. International deployment would require controlled feedstock specifications, chemical-safety screening, full-scale product testing, third-party conformity assessment and approval under the jurisdiction in which the product is placed on the market.

4.5 Pathways Toward Real-World Integration

Resource recovery programs will need to be integrated into the larger urban waste management and housing development policies if they are to be successful. Real-life validation of pilot projects involving waste recovery cooperatives, construction companies and local authorities may generate data on the various performances in field, and increase practitioners' confidence. Demonstration projects can also be used as advocacy tools to influence policy and investment decisions that favour circular resource systems in the built environment.

5. Conclusion

This study evaluated the mechanical and physical behaviour of gypsum composites containing source-defined post-consumer e-waste plastic and purchased glass fibre, together with exploratory numerical models. Within the experimental formulations, the mixture with nominal proportions of 15% e-waste plastic and 10% glass fibre gave the highest observed compressive (33.0 MPa) and flexural (10.8 MPa) mean strengths and the lowest reported density.

Based on these descriptive findings, the developed hybrid composite warrants further evaluation for non-structural interior applications, including ceiling panels, decorative wall claddings and prefabricated partition boards. Commercial implementation requires further investigation into fire endurance, smoke toxicity, thermal insulation performance, and accelerated durability testing under varied ambient conditions. The results were formulation-dependent: the plastic-only Sample B had lower mean compressive and flexural strengths than the pure-gypsum control, while hybrid Samples C and E had higher mean values. Among the formulations tested, the mixture with nominal proportions of 15% plastic and 10% glass fibre gave the highest observed mean strengths

and the lowest reported density and water absorption. This descriptive performance supports further laboratory-scale evaluation for non-structural interior components only; it does not establish fitness for construction use or product certification. Thermal performance, fire resistance, durability and long-term environmental stability were not investigated. Accordingly, no conclusion is drawn regarding these properties, in-service performance or readiness for commercial application.

Beyond material development, the study indicates a potential decentralised valorisation pathway for e-waste in construction-material supply chains. Under the conditional dry-mass interpretation stated in Section 4.3, the illustrative mass-balance for mixture E is approximately 290 kg of post-consumer plastic per cubic metre of composite. No quantitative embodied-carbon reduction is claimed; a complete material and energy inventory is required for that assessment. The decentralised model offers a potential approach to scaling up circular-economy practices in Nigeria's infrastructure-constrained environments. The laboratory results and conditional mass-balance indicate a possible resource-recovery benefit, while full life-cycle validation remains necessary. The model may also strengthen local supply streams for informal waste recovery and construction-material demand.

Future work should use FTIR with complementary DSC, TGA and Raman spectroscopy to identify the polymer composition, use XRF to screen elemental constituents, and test replicate feedstock batches to quantify compositional variability. Further research should also address large-scale implementation, life-cycle assessment and standardisation for formal construction practice. Future mechanical testing should use a larger, prospectively justified replicate set and a planned inferential analysis, including checks of distributional and variance assumptions before comparing formulations.

Before any construction or commercial claim, future work should evaluate full-scale interior components for reaction to fire, flame spread and smoke/toxic emissions; thermal conductivity; moisture and thermal cycling; accelerated ageing and weathering; creep and other long-term durability; environmental leaching and stability; and standards-based product conformity.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Abdul-Qudus Olajide Akindele, Modupe A. Onitiri; **data collection:** Abdul-Qudus Olajide Akindele; **formal analysis and simulation:** Abdul-Qudus Olajide Akindele; **analysis and interpretation of results:** Abdul-Qudus Olajide Akindele, Modupe A. Onitiri, Praise Adeola Ogunniyi; **draft manuscript preparation:** Abdul-Qudus Olajide Akindele, Praise Adeola Ogunniyi; **supervision, validation and project administration:** Modupe A. Onitiri. All authors reviewed the results and approved the final version of the manuscript.*

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